U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL WEATHER SERVICE
SYSTEMS DEVELOPMENT OFFICE
TECHNIQUES DEVELOPMENT LABORATORY

TDL Office Note 77-12

AUTOMATED PREDICTION OF THE CONDITIONAL PROBABILITY OF FROZEN PRECIPITATION FOR ALASKA

David B. Gilhousen

August 1977

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1. INTRODUCTION

Since November 1972, the Techniques Development Laboratory has been providing automated conditional probability of frozen precipitation (PoF) forecasts for 233 stations in the conterminous United States. These forecasts, made twice daily, are produced from equations made with the model output statistics (MOS) techniques (Glahn and Lowry, 1972). Comparative verification has shown that MOS forecasts are generally better than those produced on station (Bocchieri et. al., 1977; Bocchieri and Glahn, 1976). In this paper, we describe the development and testing of PoF equations for the 14 Alaskan stations listed in Table 1.

Development of the PoF forecast system consisted of two basic steps. First, for each of the 14 stations, we found a "50%" value for each of our five predictors from the National Meteorological Center's Primitive Equation (PE) model (Shuman and Hovermale, 1968). For example, we found the value of the 1000-500 mb thickness which indicates a 50-50 chance of frozen precipitation at a particular station, provided precipitation occurs. Secondly, the deviations from the 50% value were determined for each station for each variable and each day in our data sample. These deviations then became our predictors for the multivariate logit model (Brelsford and Jones, 1967) which produced our PoF equations. In order to get better results, data from several adjacent stations were combined into three regional pools of data before the equations were produced.

For our purpose, "frozen" precipitation is defined as some form of snow or sleet (ice pellets); freezing rain and mixed rain and snow are included with rain and drizzle in the "unfrozen" category. For simplicity, in this paper the terms snow (rain) and frozen (unfrozen) will be used interchangeably.

2. DERIVATION OF 50% VALUES

For our study, we used all available data from October 1972 through March 1976. We decided to not limit our developmental data sample to any particular season of the year because the only rain cases for northern Alaskan stations occur in mid-summer. We had a sufficient number of cases of snow at southern Alaskan stations and a sufficient number of rain cases at northern sites for reliable 50% values to be determined at all stations.

We used the logit model to determine the 50% values of five variables forecasted by the PE model. These five predictors were 1000-500 mb thickness, 1000-850 mb thickness, 850-mb temperature, boundary layer potential (B.L.P.) temperature, and boundary layer wet bulb (B.L.W.B.) temperature. The first four predictors have been used in our PoF operational system for the conterminous United States. B.L.W.B. temperature was intoduced as a new predictor because it contains information on low level moisture content that could be helpful on days when evaporative cooling determines precipitation type.

The logit model produces a means of fitting a sigmoid or S-shaped curve when the dependent variable (Y) is binary and the independent variable (X) is continous. From it, the probability of the binary variable having the value of one can be expressed.

$$P\ [Y = 1 | X] = \frac{1}{1 + \exp(a + bX)}$$

The computer program we used determines the maximum liklihood estimates for the model parameters a and b.

We will use B.L.P. temperature as an example of how the 50% values of the five variables were found. Forecasts from the PE model were available at 6-h intervals, as were the surface observations. Forecasts for four projection times--6-, 12-, 18-, and 24-h--from both the 0000 and 1200 GMT PE model runs were combined into one sample. This pooling of data insured that the sample contained an adequate number of both rain and snow cases at any one station. The resulting sample sizes ranged from 1,112 at Anchorage to 3,231 at Juneau. A typical example of this analysis is shown in Fig. 1. The resulting 50% value of B.L.P. temperature for Fairbanks is 284.6K.

The 50% values for all 5 variables are given in Table 1. It is apparent from Table 1 that the 50% value varies with the station's maritime influence. Stations with a maritime influence are situated so that low-level air trajectories will usually have an overwater history. In those precipitation cases when the 1000-500 mb thickness indicates a 50-50 chance of snow, the temperature sounding will exhibit a steeper lapse rate at stations with a maritime influence than at other stations. Therefore, for a given low-level temperature, the 50% thickness value at Annette (close to the Pacific Ocean) is lower than at Fairbanks (in the Interior). Note that Barrow, Barter Island, Kotzebue, and Nome have high 50% values despite their locations near the Beaufort or Bering sea. The presence of ice cover on these water bodies for much of the year makes the climate continental. Also, we could not see any variation of 50% value with elevation because the highest elevation of any of our 14 stations is less than 300 m.

3. DETERMINATION OF REGIONS

A multivariate logit model provides a means for obtaining estimates based on more than one independent variable. The estimation equation can be written

$$P\ [Y = 1 | X_1, X_2 \ldots, X_n] = \frac{1}{1 + \exp(a + b_1X_1 + b_2X_2 + \ldots. + b_nX_n)}$$

for n independent variables.

When we derived the PoF equations for the conterminous United States, we combined data from all stations before deriving the final equation. We did this by transforming our predictors into deviations from the 50% values. In doing this, we made the assumption that a particular deviation from a station's 50% value will produce the same probability of snow (or rain) at all stations.

After we looked at many logit curves, however, we observed that the shape of several of the predictor curves varied with location. This tends to violate our assumption. For example, Fig. 2 shows the logit model's probability of frozen precipitation as a function of PE B.L.P. temperature at Anchorage. A 5°C increase in PE B.L.P. temperature from the 50% value produces less of a change in the relative frequency of snow at Anchorage than at Fairbanks. One way to overcome this problem is to group stations together that have similar logit curve shapes. Each group is called a region.

In order to arrive at regions, we calculated the 90% value minus the 50% value for two predictors, B.L.W.B. temperature and 1000-850 mb thickness. These values are plotted in Fig. 3 along with the regions we arrived at. We chose these two predictors because they were the first two to be selected in a generalized screening regression experiment. Notice that higher 90%-50% values for 1000-850 mb thickness occur at North Slope and Panhandle stations. Evidently, 1000-850 mb forecast thicknesses do not distinguish between rain and snow events at these locations as well as they do elsewhere. Therefore, we decided to group the two North Slope stations together, to group the Panhandle stations (including Anchorage) together, and to group all the remaining stations together.

To see if our regionalization scheme was successful, we developed and tested regionalized equations along with a generalized equation that combines all Alaskan data. In this experiment, we chose 0000 GMT PE model output to predict the 12- and 24-h conditional occurrence of frozen precipitation. The development data sample consisted of all PE dates from October 1972 to March 1976. We tested the prediction equations on April 1976 to March 1977 data. In addition to the five meteorological variables. we used the sine and cosine day of the year as predictors. Each equation had ten predictors. It is not necessary to use PE predictors valid at the same time as the PoF forecast. For instance, if we want a probability forecast 36 hours after the 0000 GMT PE model run time, we can use the PE B.L.P. temperature forecast valid at 36 and 48 hours after run time.

Table 2 shows the verification results of this experiment. The P-scores (Brier, 1950) are shown for generalized and regionalized equations for both 12- and 24-h forecasts. Other verification scores used were percent correct, bias, Heidke skill score, and threat score. These scores were obtained by defining a MOS PoF forecast of 50% or greater to be a categorical forecast of snow. For 12-h forecasts, regionalized equations produced

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[1] Bias is defined here as the number of snow events forecast divided by the number observed. The skill score = (R-E)/(T-E), where R is the number of correct forecasts (all categories), T is the total number of cases in the sample, and E is the expected number correct by chance computed from the marginal totals of the contingency table. Threat score = C/(F+O-C) where C is the number of correct snow forecasts and F and O are the number of snow forecasts and observations respectively.

better results for all scores except for bias. For 24-h forecasts, the P-score for regionalized equations was clearly better and the skill score and threat score were slightly better. The percent correct was the same for both systems and the bias was slightly better for the generalized. Based on these results, we decided to use regional equations.

4. TESTING THE NEW PREDICTOR

Before deriving the operational equations, we decided to test the additional worth of the new predictor, PE B.L.W.B. temperature. We did this because any new predictor involves adding a new subroutine to our already complex operational MOS program, and the human effort needed to debug it may be substantial. Therefore, we want to be sure an additional predictor brings an improvement to the product.

To test this, we developed regionalized equations without B.L.W.B. temperature and verified them against the equations with B.L.W.B. temperature that we had already developed. The development data sample and the verification period were the same as in the previous experiment. Table 3 shows the verification scores for both 12- and 24-h forecasts. The equations with the new predictor produce better P-scores for both 12- and 24-hr forecasts. The other scores, however, favor the equations without the new predictor for 12-h forecasts but favor the other equations for 24-h forecasts. Overall, forecasts made from equations with PE B.L.W.B. temperature hold a slight advantage. Therefore, we decided to develop our operational equations with the new predictor.

5. DEVELOPMENT OF OPERATIONAL SYSTEM

Separate logit forecast equations were derived for each of the PE run times (0000 and 1200 GMT), for each of the three regions, and for each of the seven projections (12, 18, 24, 30, 36, 42, and 48 hours). This gives a total of 42 equations. Table 4 gives the predictors used for two of the projections. Projection, in each case, refers to the number of hours after PE model run time. The logit computer program doesn't have a screening option; therefore, we selected the 10 predictors subjectively.

5. VERIFICATION

We carried out a verification experiment in order to determine how our automated forecasts compare with those prepared at Weather Service Forecast Offices (WSFO's) in Alaska. In particular, we verified 0000 GMT 24-h objective PoF forecasts and subjective NWS local forecasts of precipitation type for Juneau, Fairbanks, and Anchorage made from October 1976 through March 1977. We verified only the cases where the local probability of precipitation forecast for the 12-24 h forecast period was 30% or greater. This eliminates many of the cases where the forecaster may have put little effort into the rain versus snow decision because he thought precipitation was unlikely.

Tables 5 and 6 show the results of this verification. Local forecasts were clearly superior to MOS forecasts in this sample although the bias of the locals was rather low. Most of the forecasts verified were at Juneau and Anchorage because of the higher frequency of precipitation there. Perhaps the PE model has special difficulty forecasting the low level temperature structure in this area of coastal mountains and fjords. Figure 3 shows that Juneau and Anchorage have higher 90-50% values than stations in Region 2. Therefore, MOS PoF should perform better in Region 2.

ACKNOWLEDGMENTS

We thank George Hollenbaugh of TDL for assistance in preparing the data for the MOS versus local forecast verification. We are also grateful to the Technical Procedures Branch of the Office of Meteorology and Oceanography for providing us with the local forecasts.

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Table 1. The 50% values of 1000-500 mb thickness, 850-mb temperature, boundary layer potential (B.L.P.) temperature, boundary layer wet-bulb temperature, and 1000-500 mb thickness for fourteen Alaskan stations.

Station Name	Location Identifiers	1000-500 mb Thickness (m)	850 mb Temperature (°C)	B.L.P. Temperature (°C)	B.L. Wet-Bulb Temperature (°C)	1000-850 mb Thickness(m)
Anchorage	ANC	5333	-2.5	10.8	-3.1	1302
Annette	ANN	5214	-6.2	4.3	-3.3	1280
Barrow	BRW	5366	-1.1	4.2	2.6	1307
Barter Island	BTI	5370	-0.5	5.7	2.1	1311
Bethel	BET	5324	-3.2	4.5	0.4	1299
Cold Bay	CDB	5293	-4.4	3.9	0.6	1297
Fairbanks	FAI	5350	-1.6	11.5	-2.2	1306
Juneau	JNU	5246	-5.2	8.2	-8.3	1278
King Salmon	AKN	5301	-3.7	5.3	-0.5	1299
Kotzebue	OTZ	5334	-3.3	4.4	-0.8	1297
McGrath	MCG	5343	-2.4	6.5	0.6	1304
Nome	OME	5331	-3.4	2.4	-0.7	1295
St. Paul Island	SNP	5319	-3.5	4.3	1.2	1299
Yakutat	YAK	5251	-4.9	7.9	-7.1	1281

Table 2. Verification Scores for regionalized and generalized Alaskan PoF equations.

Verification Score	12-h Projection		24-h Projection	
	Generalized	Regionalized	Generalized	Regionalized
P-Score	.1149	.1102	.1275	.1251
Percent Correct	.9230	.9245	.9108	.9108
Bias	1.017	1.017	1.026	1.037
Skill score	.8414	.8445	.8185	.8188
Threat score	.8303	.8333	.8136	.8146

Table 3. Verification scores for regionalized equations with boundary layer wet-bulb temperature as a predictor and regionalized equations without this predictor.

Verification Score	12-h Projection		24-h Projection	
	With	Without	With	Without
P-score	.1102	.1149	.1251	.1292
Percent Correct	.9245	.9260	.9108	.9092
Bias	1.017	1.017	1.037	1.045
Skill Score	.8445	.8447	.8188	.8157
Threat Score	.8333	.8364	.8146	.8122

Table 5. Contingency table for 0000 GMT MOS and local 24-h forecasts. Includes all independent data cases for Juneau, Fairbanks, and Anchorage where the 12-24 h local PoP forecasts were 30% or greater.

Observed	MOS Forecasts		Locals Forecasts		Total
	Snow	Rain	Snow	Rain	
Snow	21	7	23	5	28
Rain	7	62	1	68	69
Total	28	69	24	73	97

Table 6. Verification scores computed on data shown in Table 5.

Score	MOS	Locals
Percent Correct	85.6	93.8
Bias	1.00	.857
Skill Score	.797	.915
Threat Score	.600	.793

Table 4. Predictors in the PoF equations for two projections.

12-h equations		36-h equations	
Predictor	Projection (h)	Predictor	Projection (h)
Sine Day of Year	--	Sine Day of Year	--
Cosine Day of Year	--	Cosine Day of Year	--
1000-500 mb Thickness	12	1000-500 mb Thickness	36
1000-850 mb Thickness	12	1000-850 mb Thickness	36
B.L.P. Temperature	12	B.L.P. Temperature	36
B.L.W.B. Temperature	12	B.L.W.B. Temperature	36
850-mb Temperature	12	850-mb Temperature	36
850-mb Temperature	6	850-mb Temperature	48
850-mb Temperature	18	1000-850 mb Thickness	48
1000-850 mb Thickness	18	B.L.W.B. Temperature	48

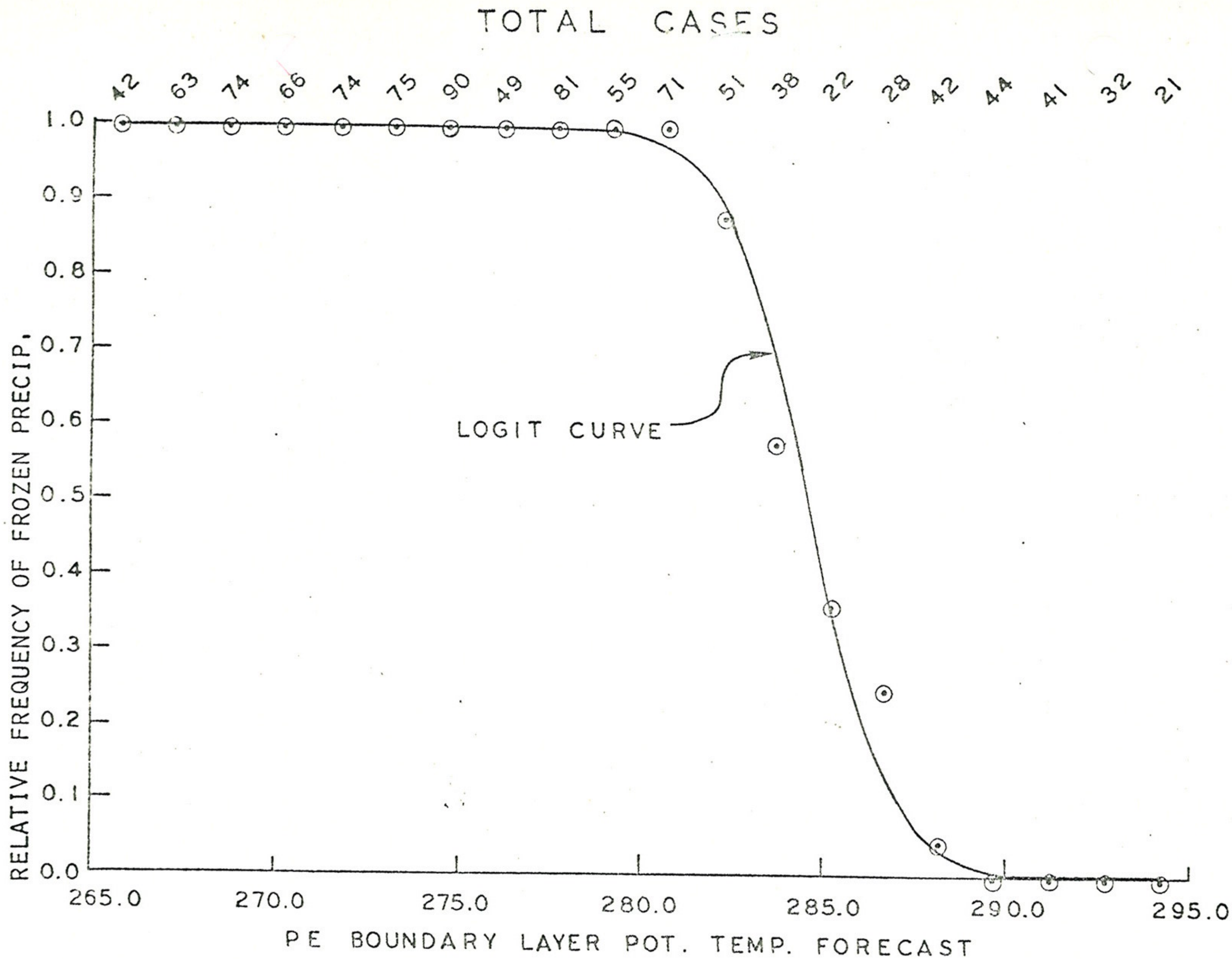

Figure 1. Probability of frozen precipitation as a function of PE boundary layer potential temperature forecast at Fairbanks, Alaska. The relative frequency of snow is plotted as ⊙ in 1.5°C intervals.

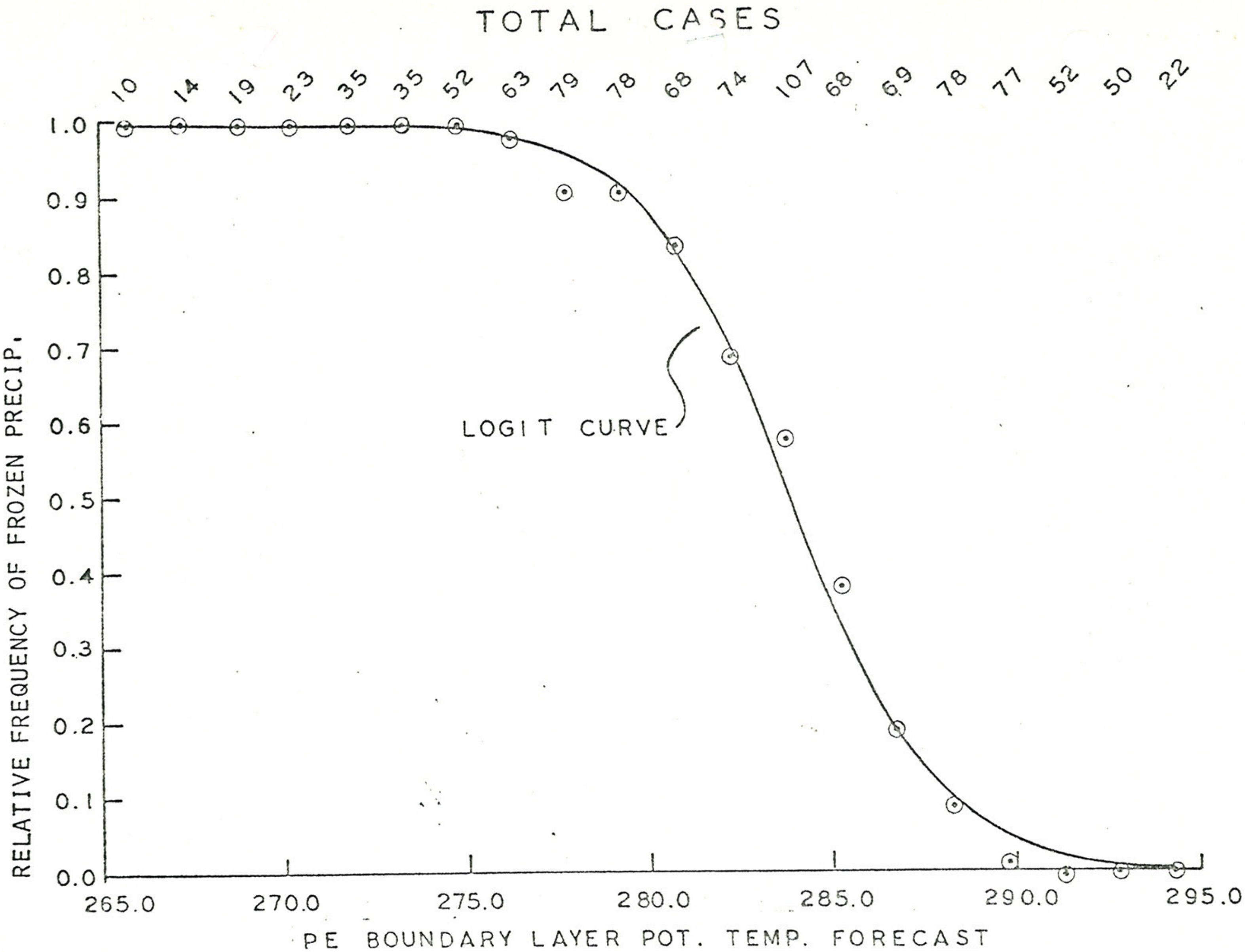

Figure 2. Same as Fig. 1 except at Anchorage, Alaska.

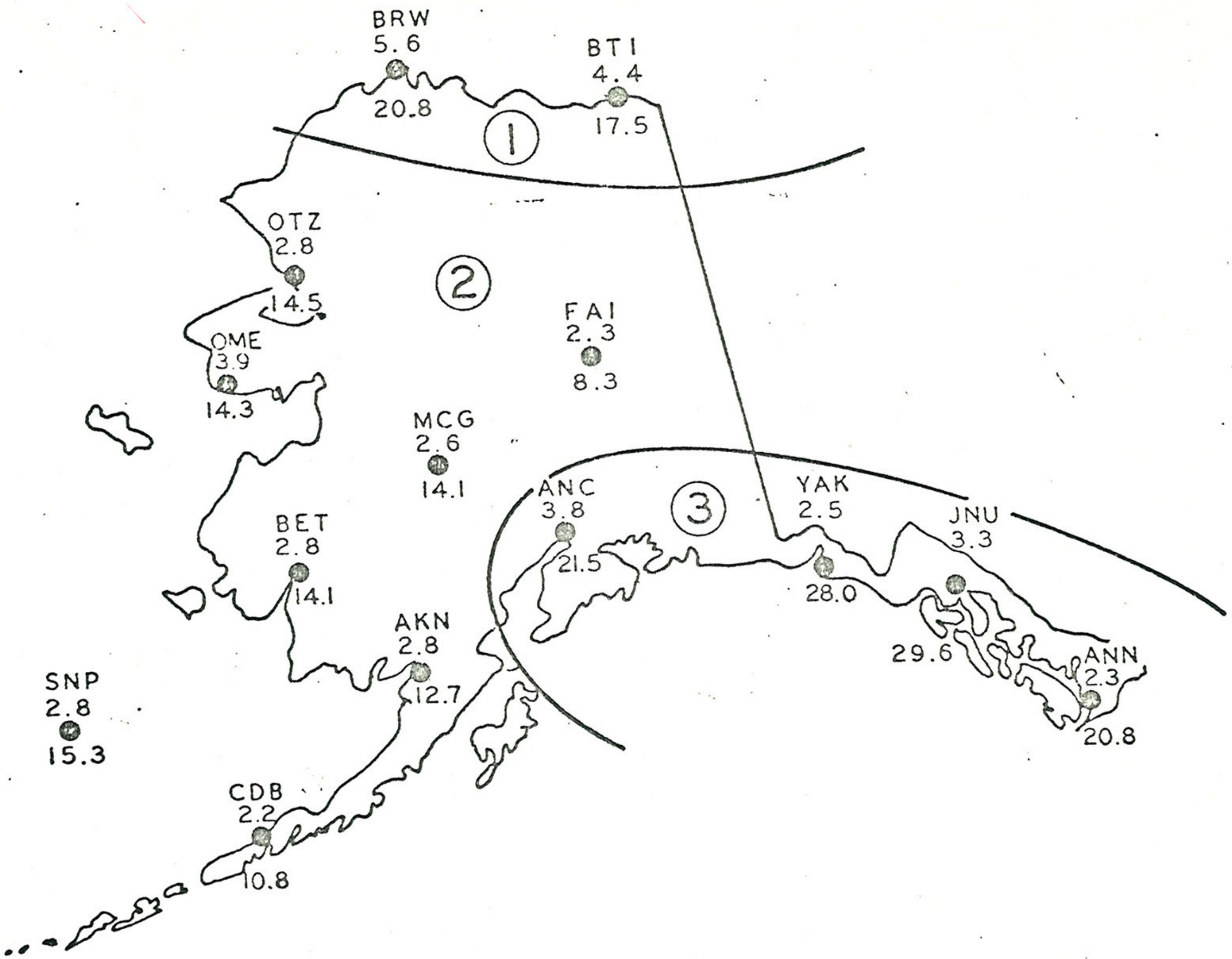

Figure 3. Station 90%-50% values and the three regions we arrived at for Alaskan PoF. 90%-50% values in °C for PE B.L.W.B. temperature forecasts are plotted above the station location; 90%-50% values in meters for 1000-850 mb thickness are plotted below.